

# LIFE TIME OF CARBON STRIPPING FOILS FOR THE SPALLATION NEUTRON SOURCE\*

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## Abstract

SNS requires thick carbon stripping foils (200 to 400  $\mu\text{g}/\text{cm}^2$  thick) to minimize the injection loss due to  $\text{H}^0$  emerging from the foil and the circulating beam loss due to Coulomb and nuclear scattering on the foil. Lifetimes of different types thick carbon foils had been measured in BNL Linac, using a 750 keV 6.7 Hz  $\text{H}^-$  beam. Beam current ( $\sim 2$  mA over a beam pulse) was selected such that the energy deposition on the foil would be equivalent to that by the SNS injected beam, which will be a 1 GeV 60 Hz  $\text{H}^-$  beam with a maximum average beam current of 2 mA (or 32 mA over a beam pulse). The tested foils included commercial carbon foils (made by Arizona Carbon Foil Co.), LANL carbon foils (by the mCADAD method), and diamond films prepared from a silicon wafer with a diamond film coating (made by Goodfellow Corp.). Foils were either single-layered or double-layered and were either with or without carbon fiber supports. The results showed that the diamond film had the longest lifetime. The relationship between the foil lifetime and the expected maximum temperature on the foil is also presented in the paper, using the 200  $\mu\text{g}/\text{cm}^2$  thick Arizona carbon foils, which are supported by 5  $\mu\text{m}$  diameter carbon wires.

## 1 INTRODUCTION

The Spallation Neutron Source (SNS) will use a carbon foil to strip the electrons from the  $\text{H}^-$  beam, provided by the Linac, before injecting into the accumulator ring [1,2]. The 1 GeV  $\text{H}^-$  beam from Linac has a pulse length of 1 ms with a repetition rate of 60 Hz and an average current of 2 mA. In order to minimize the injection loss due to  $\text{H}^0$  emerging from the foil and the circulating beam loss due to Coulomb and nuclear scattering on the foil, foil thickness should be over 200  $\mu\text{g}/\text{cm}^2$  [2].

Lifetime of the stripping carbon foils primarily depends on three factors: beam current density, foil thickness, and foil preparation method [3]. Due to the scattering of the  $\text{H}^-$  beam inside the carbon foil, increasing the beam current density on the foil and the foil thickness would produce a higher temperature on the carbon foil [4]. When the foil temperature is low ( $< 800$  K), the foil fails mainly due to the radiation damage and when the foil temperature is high ( $> 1300$  K) the sputtering effect becomes more dominated and consequently would shorten the foil lifetime significantly [3,5]. Foil

preparation method includes foil production method, foil mounting method and foil preconditioning method. Several techniques, which produce long-lived carbon stripping foils (such as: mCADAD method [6], MIBS method [6], sputtering method with nitrogen gas [6], and laser ablation deposition method [7,8]), had been reported previously. Among them, the mCADAD method is so far the only one, in addition to the standard commercial carbon foils, that can practically produce a carbon stripping foil over 100  $\mu\text{g}/\text{cm}^2$  thick [9,10]. Supporting the carbon stripping foil with thin ( $\sim 5$   $\mu\text{m}$ ) carbon wires and preheating the foil for a short time before the use were also reported as being able to improve the foil lifetime by a factor of three [9,10].

A few measurements on the lifetime of carbon stripping foils can be found in the literature [3,5,6,9]. Most of them were tested with a low DC beam current ( $< 5$   $\mu\text{A}$ ) and with a beam size of 2 ~ 3 mm. Recently Borden [10] and Sugai [9] used a higher beam current ( $\sim 85$   $\mu\text{A}$ ) to test their carbon foils in LANCE and showed that the carbon foils, made by the mCADAD method, had the longest lifetime. This current, however, is still much lower than what will be used in SNS (an average current of  $\sim 2$  mA).

In this paper, lifetime of carbon foils (made by Arizona foil Co. [12] and by LANL (using the mCADAD method) [10]) and the diamond films (prepared from Goodfellow's silicon wafer, with a diamond film coating [13]) were tested, using the 750 keV 6.67 Hz  $\text{H}^-$  beam in BNL Linac. The tested foils were either 400 or 200  $\mu\text{g}/\text{cm}^2$  thick. Two different mounting methods, with or without carbon fiber supports, were also evaluated. Beam current was selected such that the maximum temperature on the foil would be the same as that caused by the SNS injected beam. (See Section 2.) Lifetimes of tested carbon stripping foils are summarized in Section 3.

## 2 DETERMINE BEAM CURRENT FOR THE TEST

The beam parameters of the SNS injected beam and the test beam in BNL Linac are as follows: (Both are  $\text{H}^-$  beam)

	KE	Length	Freq.	Max. Current	Beam size
SNS	1 GeV	1 ms	60 Hz	32 mA	3mm x2mm
Linac	750keV	0.5ms	6.7Hz	2.02/ 2.2 mA	3 mm dia.

After integrating Eq. (4) in Ref [4], using the SNS beam parameters above, the maximum temperatures on the carbon foils would be 2350 K and 2578 K for the 200  $\mu\text{g}/\text{cm}^2$  and the 400  $\mu\text{g}/\text{cm}^2$  thick foil respectively.

\*Work performed under the auspices of the U.S. Department of Energy.

Similarly, by using the same mathematical model and the Linac beam parameters above, the required power densities to produce the foil temperatures above can be determined. They are  $15.9 \text{ MW/m}^2$  and  $34.3 \text{ MW/m}^2$  for the  $200 \text{ } \mu\text{g/cm}^2$  and the  $400 \text{ } \mu\text{g/cm}^2$  thick foil respectively. The required beam current could be calculated by the following equation:

$$I = P \cdot A / S_p \quad (1)$$

where  $I$  is the test beam current [A],  $P$  is the required power density on the foil [ $\text{W/m}^2$ ],  $A$  is the beam cross section area  $= 7.07 \times 10^{-6} \text{ m}^2$  and  $S_p$  is the stopping power of the 750 keV H<sup>+</sup> beam in the carbon [14] = 55.6 keV and 110.4 keV for the 200 and 400  $\mu\text{g/cm}^2$  case. (which includes the energy loss of a 750 keV proton beam through carbon foil and the energy to stop two electron beams in the H<sup>+</sup> beam). The required beam currents, calculated from Eq.(1), are 2.02 mA and 2.20 mA for the 200 and 400  $\mu\text{g/cm}^2$  case.

### 3 LIFETIME TESTS

#### 3.1 Test Setup

The test set-up includes a viewing box, an upstream current transformer, a collimator (a graphite plate with a 3 mm diameter aperture), a 10 mm x 30 mm carbon foil (mounted on an aluminum frame), a downstream Farady cup, and a data acquisition system. The foil can be rotated to a stand-by position by an external rotary drive. The collimator can be adjusted with respect to the foil position by an external x-y-z manipulator, which can bring the aperture to the position where most of the beam can pass through. The collimator is located ~5 mm away from the foil, which allows viewing the beam spot and controlling the beam size on the foil. Due to the stripping, the beam current before and after the carbon foil would have an opposite polarity, which could be used to monitor the condition of the stripping foil. In the tests, the upstream current transformer was used to monitor the stability and amplitude of the current before the foil and the downstream Farady cup was used to measure the current after the foil. The lifetime of the foil is defined as when the downstream beam current is reduced by 10% of its initial value. All the tests were performed in the beam-line vacuum chamber ( $1 \sim 2 \times 10^{-7}$  torr). Data acquisition system, Logviews (by Data Base Services Group Inc.), was used to record the upstream and the downstream currents at an interval of 1 minute.

#### 3.2 Foil Preparations

The following foils and foil preparation methods had been evaluated in the lifetime tests of the stripping carbon foil: (1) Arizona carbon foil (400 or 200  $\mu\text{g/cm}^2$  thick), LANL carbon foil (200  $\mu\text{g/cm}^2$  thick), or diamond film (~1  $\mu\text{m}$  thick) (The diamond film was prepared by removing the silicon from a silicon wafer with a diamond film coating, made by Goodfellow Corp. [13]) (See Fig. 1.), (2) with or without a preconditioning (The preconditioning process ramps the beam current from 0 to

full current in one hour before the test.), (3) with or without carbon fiber supports (Carbon foil is sandwiched with 5  $\mu\text{m}$  diameter Carbon wires and with a 3 mm pitch (see Fig. 2) to prevent the foil from excessive distortion during the beam tests.), and (4) one layered or double layered foils (The double-layered foil is assembled by partially gluing two half-thick foils together with some Aquadag, made by Acheson Colloids Co. [15].)

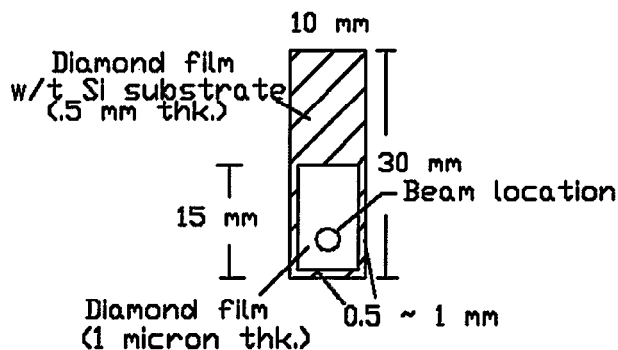


Figure 1: Configuration of the diamond film

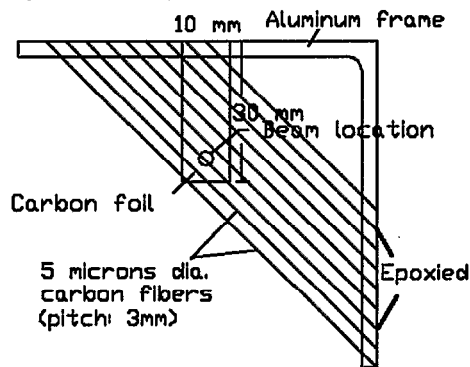


Figure 2: Carbon foil supported by carbon fibers

#### 3.3 Test Results

A summary of carbon foil lifetime tests is shown in Fig. 3. The relationship between beam current, maximum foil temperature and foil lifetime is shown in Fig.4. (200 $\mu\text{g/cm}^2$  thick Arizona carbon foils, supported by 5  $\mu\text{m}$  diameter carbon wires, were tested.)

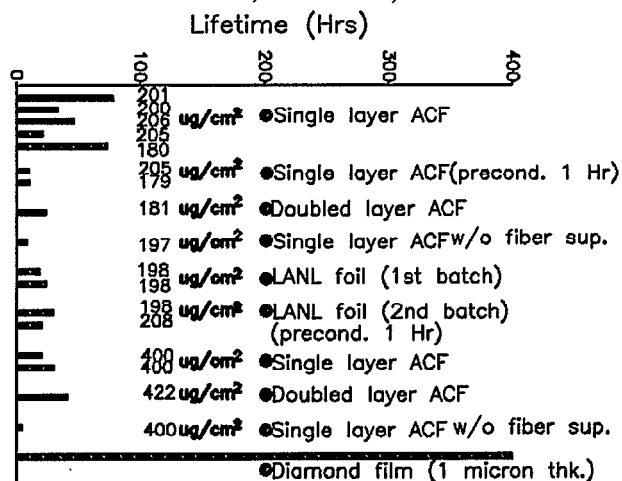


Figure 3: A summary of carbon foil lifetime tests

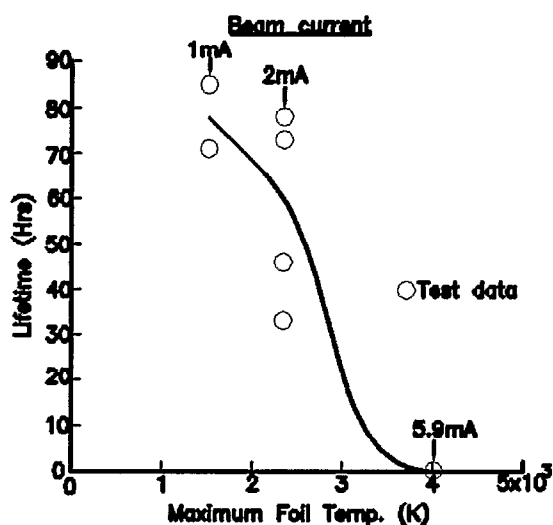


Figure 4: Carbon foil lifetime vs. maximum foil temperature for Arizona 200  $\mu\text{g}/\text{cm}^2$  foil

## 4 CONCLUSIONS

Lifetime of different type carbon stripping foils had been successfully measured in BNL Linac, using the 750 keV  $\text{H}^+$  beam, with a repetition rate of 6.7 Hz and an average beam current of 2 mA (over a beam pulse). The conclusions are as follows:

1. Unlike the previously published test results, which used a low beam current to perform the tests, Fig. 3 shows that the lifetime of the carbon foil will be shortened with a preheating process and with a higher beam current. The LANL carbon foil (by the mCADAD method) didn't show a long life under the present test condition.
2. The diamond film, window-framed by a 0.5 mm thick silicon substrate, had the longest lifetime, up to 400 Hrs. Further development is still required to eliminate silicon edges around the diamond film before it can be practically used.
3. The maximum lifetime of the Arizona carbon foil is ~78 hours, which is a 200  $\mu\text{g}/\text{cm}^2$  thick foil, single layered and carbon fiber supported.
4. From Fig. 4, the lifetime of a carbon stripping foil would decrease sharply when the foil temperature exceeds 2500 K.

## 5 ACKNOWLEDGEMENTS

The authors would like to acknowledge Brian Briscoe and Arnold Esper for their timely and skilful efforts in assisting and preparing the foil tests and John Brodowski

for continuing the search for more candidate stripping foils for the lifetime tests.

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